RESEARCH IN RADIATION PHYSICS AND AERODYNAMICS

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UNIVERSITY OF CALIFORNIA, SAN DIEGO

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TABLE OF CONTENTS

I. INTRODUCTION AND SUMMARY

The current ARPA/IPAPS program as defined in UCSD Continuation Proposal 4769 dated January 4, 1972 and in the U.S. Army Research Office-Durham Contract DAHC04-72-C-0037 dated June 12, 1972, called for the performance of advanced interdisciplinary research in support of strategic defense technologies and ARPA objectives. This research, with primary emphasis on the physics of turbulent flow, plasmas and lasers, shall include but not necessarily be limited to the following areas:

a. Wake Turbulence and Atmospheric Boundary Layers. Experimental and theoretical studies involving variable temperature effects, entrainment, mixing, chemical reactions in both wake turbulence and atmospheric boundary layer as appropriate, and also turbulence in stratified flows.

b. Turbulent Mixing and Shear Flows. Basic studies of turbulent mixing and shear flows.

c. High-temperature Gas Dynamics. Basic gas dynamics research involving radiation, chemical reactions, kinetics, and turbulence.

d. Ionospheric Physics. Theoretical analysis related to an ionospheric heating experiment in which a high power radio wave transmitter was used to modify the ionosphere, including the analysis of plasma instabilities postulated as being responsible for the observed effects.

e. Laser Propagation and Advanced Technology. Theoretical and experimental studies of laser energy propagation and advanced laser technology.

f. Laser Diagnostics and Interactions. Development of laser diagnostic techniques and investigations of nonlinear interactions.

As summarized in the preceding Semi-Annual Technical Status Report (April 1, 1972 - September 30, 1972), our current research at the Institute for Pure and Applied Physical Sciences under Contract DAHC04-72-C-0037 covers twenty-six major topics. The research is being carried out by fifteen faculty members, four post-doctoral research engineers, eighteen graduate students, and a number of undergraduate summer students. A summary of the research topics, correlations with relevant ARPA programs, and technical progress up to the time of the last ARPA/STO-Institutional Research Review Briefing in Washington, D.C. (September 28, 1972) were also given in the preceding report and hence need not be repeated here. What follows is simply an updated technical status report on these various research topics.

II. HIGHLIGHTS OF RECENT ACCOMPLISHMENTS

Our major effort during the past six months has been in the re-orientation and redirection of the overall program in response to the new ARPA/STO research priorities as expressed in the September 28, 1972 Institutional Research Review Briefing. In view of the projected changes in ARPA/STO research interests over the next several years and the long lead time required to construct certain experimental apparatus, we find it desirable to start phasing in some of the new research topics that have been proposed for the next contractual year (see UCSD Proposal 5559 dated October 14, 1972, for performance period July 1, 1973 to June 30, 1974) while phasing out some of the research topics due to be discontinued. Worth special mention are those research topics involving optical imaging and underwater technology which are not specifically covered by the current work statement but understood to be of increasing importance. Considerable planning and preparatory works have been done during the past six months toward the phasing in of new experiments in these areas.

III. REPORT OF PROGRESS IN BRIEF

Referring to the six (6) research areas cited on page 2 and the topic identification numbers given in Table 1 of the preceding Semi-Annual Technical Status Report (April 1, 1972 - September 30, 1972), we are presenting here a brief report of progress during the past six months, together with a list of relevant publications, for each of the twenty-six (26) current research topics:

a. Wake Turbulence and Atmospheric Boundary Layers

Topic #1. High Temperature Entrainment

INVESTIGATORS: S. C. Lin, L. Tsang, and C. P. Wang

SUBJECT DESCRIPTION: Temperature Field Structure in Strongly-Heated Buoyant Thermals

PROGRESS IN BRIEF: The multiple discharge problem mentioned in the preceding Semi-Annual Report has been remedied by the introduction of a second Ignitron switch, which acts as a "crowbar" for short-circuiting the arc restrike current beyond the first half-cycle. Preliminary comparison of the temperature fluctuation spectra obtained from the more recent measurements involving the co-axial vertical discharge geometry with those obtained from the earlier measurements involving the horizontal discharge geometry[1] indicates that

the statistical properties of the fluctuating temperature field within the rising hot air bubble is not too sensitive to the initial conditions.

In our theoretical studies, Dr. C. P. Wang has recently developed an analytical model [2] in which the mean mass motion and turbulence intensity of the entraining thermal bubble were formulated in accordance with the conservation equations for the total mass, vertical momentum, enthalpy, and kinetic energy within the bubble. Self-similar solutions are described in terms of the properties of the ambient atmosphere, the initial density (or temperature) ratio between the inside and outside fluids, and three non-dimensional parameters, namely: the mass entrainment constant, the effective drag coefficient, and the turbulence kinetic energy dissipation rate, ϵ. From these solutions, a simple algebraic formula has also been derived for predicting the maximum height which a hot air bubble can reach in a stable atmosphere for various initial conditions and gross non-dimensional parameters. This type of analytic model is expected to be useful for general parametric studies and, perhaps, also for the checking of elaborate computer codes involving artificial assumptions concerning the fluid dynamics of turbulent entrainment.

POSSIBLE APPLICATIONS: Ivy Owl; shock-bubble interactions; tropospheric properties related to laser propagation.

PUBLICATIONS:

1. S. C. Lin, L. Tsang, and C. P. Wang, "Temperature Field Structure in Strongly Heated Buoyant Thermals," Phys. Fluids 15, 2118-2128 (1972).

2. C. P. Wang, "Motion of a Turbulent Buoyant Thermal in a Calm Stably-Stratified Atmosphere," (to be published in the Physics of Fluids, June 1973).

Topic #4. Turbulence in Atmospheric Boundary Layers

INVESTIGATORS: C. W. Van Atta, T. T. Yeh, C. Winant, and Students

SUBJECT DESCRIPTION: Atmospheric Boundary Layers and Turbulence Research

PROGRESS IN BRIEF: Professor Van Atta, post-doctoral fellow T. T. Yeh, and students are continuing their basic investigations on a number of problems related to atmospheric boundary layers and stratified flows. In their recent studies, some of the statistical characteristics of the breakdown coefficient, defined as the ratio of averages over different spatial regions of positive variables characterizing the fine structure and internal intermittency in high Reynolds number turbulence, have been investigated using experimental data for the streamwise velocity derivative $\partial u/\partial t$ measured in an atmospheric boundary layer. The results indicate that the assumptions and predictions of the hypothesis of scale similarity (similar but somewhat less restrictive assumptions than those of lognormal distribution) developed by Nouikov do not adequately describe or predict the statistical characteristics of $(\partial u/\partial t)^2$.

A paper "Spectral Transfer of Scalar and Velocity Fields in Heated Grid Turbulence" which recently appeared in Journal of Fluid Mechanics, is a first direct measurement of scalar spectral transfer. For significantly extending the present measurements, Ken Helland has also been investigating the velocity spectral energy transfer in high Reynolds number turbulence by utilizing both the big jet and the big grid data. An artificial turbulent velocity field similar to the velocity field in grid generated turbulence has been produced with an electrodynamic shaker to test the ability of constant-current and constant-temperature anemometers to measure higher-order moments of velocity. Evidence is found which suggests that a constant-temperature anemometer may be more suitable than a constant-current anemometer for measurements of higher-order moments of velocity.

Since joining UCSD in September, 1972 under joint SIO-IPAPS sponsorship, post-doctoral fellow Clint Winant has been carrying out a number of laboratory studies related to stratified flows. These studies are concentrated in two different areas. The first area is concerned with the development of instrumentation for measurements in silt-stratified flows. A very low drift level single

electrode conductivity probe and associated electronics is now available, which has a spatial resolution of the order of a few millimeters. Velocity measurements are made with commercially available quartz coated hot film anemometers made by Thermo-Systems, Inc. We are presently trying to determine whether laser doppler anemometer techniques can be adopted for measurements in stratified flows.

The second area of study we have made measurements in is two different stratified flow fields. In the first case we have investigated the flow which develops upstream of a two dimensional obstacle in a stratified fluid with particular emphasis on the effect of Richardsons' number

$$Ri = -\frac{g}{\rho}\frac{d\rho}{dz}\frac{h^2}{v^2}$$

on the horizontal extent of the upstream wake.

Another problem which we are currently investigating is concerned with the unsteady flow field which develops about a capsule driven vertically through a continuously stratified fluid by its own weight.

POSSIBLE APPLICATIONS: Optics problem related to atmospheric transmission; underwater technology

PUBLICATIONS:

1. T. T. Yeh and C. W. Van Atta, "Spectral Transfer of Scalar and Velocity Fields in Heated Grid Turbulence. J. Fluid Mechanics 58, 233 (1973).

2. C. W. Van Atta and T. T. Yeh, "The Structure of Internal Intermittency in Turbulent Flows at Large Reynolds Number: Experiments on Scale Similarity," (submitted to J. Fluid Mech).

3. K. N. Helland and C. W. Van Atta, "Higher-Order Moments of Artificial Turbulence as a Response Test of Constant-Current and Constant-Temperature Anemometry, (in progress).

Topic #5. Scalar Mixing and Turbulent Shear Flow

INVESTIGATORS: C. H. Gibson, C. A. Friehe, and students

SUBJECT DESCRIPTION: Field and laboratory experiments on turbulent shear flow and scalar mixing

PROGRESS IN BRIEF: Preliminary work has begun on the investigation of the effect of refractive index fluctuations on optical propagation over land. An air conditioned van has been acquired to house turbulence, temperature and humidity detection equipment. Initial tests will be carried out at a site on the west shore of the Salton Sea. Further data analysis of FLIP measurements over the ocean show the same difference in shape between turbulent temperature and humidity spectra as noted earlier.[1,2]

Work on the analysis of turbulence data taken in turbulent stratified media has been carried out. Preliminary results indicate an unexpected turbulence signal in phase with surface waves at depths of 20 meters in the mixed layer and at 50 meters in the thermocline of the ocean off San Diego. A tentative explanation is that the diverging flow on the forward face of the waves may generate or amplify the very low levels of turbulence which exist in the ocean ($\varepsilon \sim 10^{-3}$ cm^2/sec^3). This mechanism also provides an explanation for our observation (unpublished) of intense turbulence in the air on the upwind side of surface wave crests, where the flow is also divergent. Turbulence in phase with gravity waves has apparently never been previously noted experimentally. It is apparently the dominant turbulence, and consequently must play a crucial role in the attenuation, internal mixing and possibly generation of surface and perhaps even internal waves.

POSSIBLE APPLICATIONS: Laser propagation; underwater technology

PUBLICATIONS: (Full or partial support from ARPA/IPAPS acknowledged):

1. C. A. Friehe, C. H. Gibson and G. Dreyer, "Effects of Temperature and Humidity on Density and Refractive Index Fluctuations Over the Open Ocean," presented at the Optical Society Meeting 17-20 October 1972.

2. C. A. Friehe, C. H. Gibson and G. Dreyer, "Effects of Temperature and Humidity on Density and Refractive Index Fluctuations Over the Open Ocean." Paper in progress.

3. J. P. Clay and C. H. Gibson, "Power Law Comparison for Turbulent Temperature Spectra," Bull. APS 17, No. 11, 1972.

4. C. A. Friehe, F. H. Champagne and C. H. Gibson, "Measurements of Turbulent Fluxes Over the Open Ocean," Bull. APS 17, No. 11, 1972.

5. G. F. Dreyer, C. H. Gibson and C. A. Friehe, "Measurements of Temperature and Humidity Fluctuations Over the Open Ocean," Bull. APS 17, No. 11, 1972.

6. L. A. Vega, J. P. Clay and C. H. Gibson, "Fine Scale Measurements of Velocity and Temperature in the Mixed Layer of the Ocean," Bull. APS 17, No. 11, 1972.

7. C. H. Gibson, "Turbulent Mixing and VHF Radio Wave Scattering from the D Layer of the Ionosphere, submitted to the International Symposium on Near Space Environment and Radio Communication, New Delhi, February 14-20, 1973.

8. C. H. Gibson, "Estimation of Evaporation Rates from Turbulent Humidity Fluctuation Measurements," submitted to the International Symposium on the Hydrology of Lakes, Helsinki, Finland, July 23-27, 1973.

9. C. H. Gibson and J. P. Clay, "Mechanisms of Turbulent Mixing," submitted to the XIth Biennial Fluid Dynamics Symposium on Advanced Problems and Methods in Fluid Mechanics, Kamienny Potok, Poland, 3-8 September 1973.

b. Turbulent Mixing and Shear Flows

Topic #2. Strong Temperature Mixing by Turbulence

INVESTIGATORS: S. C. Lin and Samuel Lin

SUBJECT DESCRIPTION: Experimental study of strong temperature mixing in nearly homogeneous, isotropic turbulence in a compressible fluid

PROGRESS IN BRIEF: The heating grid of our strong-temperature-mixing turbulence tunnel, which was partially damaged in the most recent series of strong mixing experiments, [3] has been repaired. The tunnel is now being prepared for use as a laboratory source of controlled refractive index fluctuations in optical propagation studies. Although these optical propagation studies are not due to begin until the next contractual year (see UCSD Proposal 5559 dated October 14, 1972, p. 15), we have already started on a series of exploratory experiments aimed at determining the quality of undisturbed and disturbed optical images that can be obtained with relatively inexpensive telescope systems. Preliminary results look very encouraging.

POSSIBLE APPLICATIONS: Optical and laser propagation; high temperature entrainment; plume physics; reentry physics; chemical laser

PUBLICATIONS:

1. S. C. Lin and S. C. Lin, "Homogeneous Turbulence with Large Amplitude Temperature-Density Fluctuation," Bull. Am. Phys. Soc., Series II, 16, 1312 (1971).

2. S. C. Lin and S. C. Lin, "A Study of a Homogeneous Compressible Turbulence Field Generated by Rapid Mixing of Hot and Cold Streams," AIAA Paper No. 72-119 (1972).

3. S. C. Lin and S. C. Lin, "A Study of Strong Temperature Mixing in Subsonic Grid Turbulence," (accepted for publication in the Physics of Fluids).

Topic #3. Turbulence in Stratified Flow

INVESTIGATORS: T. T. Yeh, C. W. Van Atta, and S. C. Lin

SUBJECT DESCRIPTION: Experimental and theoretical study of turbulence in strongly-stratified flows

PROGRESS IN BRIEF: This is a new research topic which has only been initiated during the past several months in response to recently expressed ARPA interests in problems related to interactions between turbulence and stratified flows. Since a continuous-flow facility suitable for statistical turbulence study of this type does not yet exist, our initial efforts have been in the design and construction of a multi-layer recirculating-flow water channel capable of being strongly stratified by salinity variations. The water channel will have a rectangular test section of 30 cm × 60 cm cross-section and a 500 cm length. The 12 salinity-stratified flow layers will be separately driven by 12 variable-speed motors and supplied by 12 separate salt-water storage tanks. By varying the speed of the driving motors and the salt concentration in the supply tanks, one hopes to be able to generate initial flow velocity and fluid density profiles of arbitrary shape (to the extent that they may be approximated by 12-point polynomials) up to a maximum mean flow velocity of 2 meters per second. Efforts will be made to damp out all initial flow disturbances due to propeller action, bents, and partitioning wall boundary layers before the flow enters the test section, so that controlled turbulence-stratified flow interactions can be studied down to relatively low levels. At a uniform flow velocity of 25 cm/sec under the most-stably-stratified condition, the flow channel will have a mean flow Reynolds number of 2×10^3 per cm and a channel-length/Väisälä wavelength ratio of about 6. This would bring us within range of studying the turbulent wake collapse phenomenon directly in a continuous flow facility for the first time.

At the time of writing of this progress report, construction of this strongly-stratifiable flow channel is about half-completed.

POSSIBLE APPLICATIONS: Undersea technology; oceanography

PUBLICATIONS: None

Topic #6. Turbulent Flows with Fast Chemical Reactions

INVESTIGATORS: C. H. Gibson and P. A. Libby

SUBJECT DESCRIPTION: Distribution of reactants and products near a reacting surface in unpremixed turbulent flows with very fast two-reactants chemical reactions.

PROGRESS IN BRIEF: The structure of a reacting surface in a turbulent flow involving contiguous volumes of fluid with one reactant present and the other absent has been studied by an idealized model. The analysis provides estimates of the several characteristic length scales involved and distributions of the reactants and product in the neighborhood of such a surface in fluids where the diffusivity of chemical species is much less than that of momentum (e.g., aqueous solutions). The results of an earlier experiment involving the turbulent mixing of weak-acid and weak-base solutions are discussed and are shown to provide qualitative support for the picture of reacting surfaces evolving from this study.

This work is scheduled to be phased out at the end of the current contractual year (June 30, 1973).

POSSIBLE APPLICATIONS: Undersea technology

PUBLICATIONS:

1. C. H. Gibson and P. A. Libby, "On Turbulent Flows with Fast Chemical Reactions. Part II. The Distribution of Reactants and Products Near a Reacting Surface," Combustion Science and Technology, 6, pp. 29-35 (1972). (Jointly sponsored by ARPA under Contract No. DA-31-124-ARO-D-257, ONR under Contract N00014-67-0226-0005 (Subcontract No. 4965-26) as part of Project SQUID, and NSF Grant No. GA-31439.

Topic #7. Scalar Diffusion and Space-Time Correlation in Turbulent Flow

INVESTIGATORS: P. A. Libby and Students

SUBJECT DESCRIPTION: Dispersion and diffusion of passive scalar quantities in turbulent velocity field. Space-time correlation of velocity and temperature.

PROGRESS IN BRIEF: The research works under this topic have been extensively summarized in the preceding Semi-Annual Technical Status Report (pages 19 and 20 in report for period April 1, 1972-September 30, 1972). Essentially, the main effort here concerns measurements of various statistical properties of a passive scalar in turbulent flows.

In the most recent study by John LaRue of the wake of a heated cylinder in a low-speed airstream using conditional sampling across the turbulent/non-turbulent interface, the intermittency factor distributions have been found to be similar. Conditioned point statistics of the temperature fluctuations and space-time correlations of the intermittency function and temperature fluctuation show that there is a definition structure to the interface and additionally that the temperature statistics in portions of the flow not near the interface are nearly independent of transverse location. The slope statistics show that at least 30% of the downstreams interfaces "overhang" and that large-scale engulfment may be an important mechanism in growth of free turbulent shear flow.

At the present time, long time autocorrelations of the intermittency function are being produced in an effort to ascertain the presence of large-scale periodic structures in the flow. (John LaRue's work was supported 50% by ARPA and 50% by AFOSR under the THEMIS program.)

Even though these works were originally motivated by the hypersonic wake problem in reentry physics, some of the experimental techniques and results are applicable to the high-temperature entrainment and rocket plume problems. With suitable modifications (e.g., changing the working fluid from air to water), some of the experimental and analytical techniques can also be used in the study of turbulent dispersion and diffusion problems related to undersea technologies.

Due to funding limitation, this work is scheduled to be phased out at the end of the current contractual year (June 30, 1973).

POSSIBLE APPLICATIONS: Reentry physics; high-temperature entrainment; plume physics; undersea technology.

PUBLICATIONS:

1. P. A. Libby and C. Scragg, "On the Diffusion of Heat from a Line Source Downstream of a Turbulent Grid," (submitted to the AIAA Journal).

c. High-Temperature Gas Dynamics

Topic #8. Combustion Instability and Laser

INVESTIGATORS: F. A. Williams and student

SUBJECT DESCRIPTION: Study of L^* instability[1] in solid rocket combustion chambers, with possible application to visible chemical laser generation.

PROGRESS IN BRIEF: This is a research topic proposed only recently by Professor F. A. Williams and one of his students. An L^* burner[1] with transparent side walls would be constructed should extra funds become available. Using JPN (a double-base nitrocellulose-nitroglycerine solid propellant[2]) as liner, the burner is designed to operate at chamber pressures from 1 to 5 atmospheres, and at oscillation frequency from 1 to 100 Hz. Spectra would be taken, both with and without an optical cavity, with time resolution better than 10 msec. It is proposed to scan the visible spectrum for signs of lasing on a time-resolved basis. Special attention will be paid to the electronic bands of CO and NO. Since nitrocellulose self-deflagrates at pressures below 5 torr, thought will be given to the construction of reduced-pressure chambers for L^* instability. The experimental work is relatively straightforward, but at present the chance of obtaining interesting results apparently cannot be estimated theoretically.

On account of funding limitation, it does not appear possible that the proposed experiment can be carried out under the ARPA/IPAPS program. Accordingly, this work will be terminated at the end of the current contractual period (June 30, 1973).

POSSIBLE APPLICATIONS: Plume physics; laser technology

PUBLICATIONS: None

References:

1. M. Barrere, A. Jaumotti, B. Fraeijs de Veubeke, and J. Vandenkerckhove, Rocket Propulsion (Elsevier Publishing Co., New York, 1960), p. 653.

2. M. Barrere et al., loc. cit., p. 208.

Topic #9. Effects of Radiation on Blast Waves

INVESTIGATORS: D. B. Olfe and student

SUBJECT DESCRIPTION: Effects of radiative transfer on blast wave propagation and structure.

PROGRESS IN BRIEF: Research has been completed on the effects of transparent gas radiation on blast waves. This work has relevance to blast waves produced by focused laser radiation, as well as to supernovae remnants. The only previous theory for a point explosion with transparent gas radiation is the astrophysicists' crude model of a blast wave which starts out adiabatically, and then, when radiation becomes important, the flow instantaneously switches over to a momentum-conserving shell (zero interior pressure). Our analytical work shows that in general the transition to the momentum-conserving shell is not complete since the cooling wave has a decreasing rate of propagation into the interior. Our direct numerical computations confirm the long-time behavior of our analysis and also provide the details of the transition period. This work is completed with publication #3 below.

POSSIBLE APPLICATIONS: Plume physics; dynamics of shock waves produced by focused laser radiation in gases; momentum and energy transfer in pulsed laser-solid interactions; astrophysics.

PUBLICATIONS:

1. D. B. Olfe and F. Y. Su, "Radiative Transfer Effects on Reflected Shock Waves. I. Transparent Gas," Phys. Fluids 14, 2636 (1971).

2. D. B. Olfe and F. Y. Su, "Radiative Transfer Effects on Reflected Shock Waves. II. Absorbing Gas," Phys. Fluids 15, 263 (1972).

3. Gary G. Erickson and D B. Olfe, "Nonsimilar Blast Waves with Transparent Gas Radiation," submitted to Phys. Fluids; also, abstract has been submitted for possible presentation at the 4th International Colloquium on Gasdynamics of Explosions and Reactive Systems, July 10-13, 1973 at UCSD.

Topic #10. Two-Dimensional Radiative Transfer; Rayleigh-Taylor Instability

INVESTIGATORS: D. B. Olfe and student

SUBJECT DESCRIPTION: Comparison of analytical and numerical methods for treatment of two-dimensional radiative transfer problems; study of Rayleigh-Taylor instability in shock layers.

PROGRESS IN BRIEF: Two-dimensional radiative transfer studies are being carried out in order to test and develop computational methods. Essentially all past work has involved the one-dimensional approximation to the radiative transfer. As an example problem we have computed the radiative equilibrium temperature distribution in a gray gas within a rectangular enclosure, with its walls at different temperatures. Calculations are carried out analytically using our previously developed "modified differential approximation," and compared with numerical computation using Hottel's zonal method. The publication listed below represents completed work on this problem.

Study of Rayleigh-Taylor instability is being carried out. First, the radiating blast wave of Topic #9 above shows very large accelerations and decelerations during the transition period, which may result in instabilities producing the "turbulent" structure observed in supernovae remanents. Another Rayleigh-Taylor instability problem being considered involves a stagnation point between two fluids. Such a study should indicate the stability of ablation layers under high decelerations, experienced, e.g., by a Jupiter probe or by a vehicle with a very high earth reentry velocity. Both analysis and very simple laboratory experiments are being carried out on this stagnation point stability problem.

POSSIBLE APPLICATIONS: Ivy Owl; plume physics; high-temperature entrainment; reentry physics.

PUBLICATIONS:

1. L. Glatt and D. B. Olfe, "Radiative Equilibrium of a Gray Medium in a Rectangular Enclosure," J. Quant. Spectros. Radiat Transfer (in press).

Topic #11. Gas-Surface Interactions

INVESTIGATORS: D. R. Miller and student

SUBJECT DESCRIPTION: Molecular beam studies of gas-surface interactions when inert and reactive gas atoms or molecules in the energy range 0.006-2 eV are impinged on metallic surfaces.

PROGRESS IN BRIEF: Having completed our studies of monatomic inert gases, we are now beginning to study inert and reactive polyatomic gases. We have preliminary data for simple diatomics, N_2, O_2, CO, on silver which has been compared favorably to a classical theory developed by another colleague, not within IPAPS. However, our principal effort has been directed at constructing (with existing equipment) an apparatus to study the interaction of fluorine atoms and molecules with metals. We have chosen fluorine because of its interest as a strong oxidizer, because of its presence in the important HF, DF chemical lasers, and because it represents a molecule which is easily dissociated, and whose internal degrees of freedom can be adjusted independently in our beam sources; in fact, a side product of this research will be a direct determination of the rotational relaxation of F_2. We feel that we will therefore be able to examine the effects of internal states on surface dissociation, recombination, and reaction.

We have completed the fluorine gas handling system, the fluorine trapping system which protects our pumps, and the surface heater units. We have also completed theoretical calculations of the free-jet expansions of F_2, and F_1F_2 mixtures. Experiments are waiting on the final machining of vacuum parts, which is in progress.

POSSIBLE APPLICATIONS: Plume physics; mid-course phenomena; chemical lasers.

PUBLICATIONS:

1. D. R. Miller and R. B. Subbarao, "Properties of 0.01 eV Helium Atoms Scattered Inelastically from Silver (111)," J. Vacuum Science and Technology 9, 808 (1972).

2. D. R. Miller and R. B. Subbarao, "Velocity Distribution Measurements of 0.06-1.4 eV Argon and Neon Atoms Scattered from the (111) Plane of a Silver Crystal," J. Chem. Phys. (in press).

Topic #12. Chemical Reactions in Crossed Molecular Beams

INVESTIGATORS: D. R. Miller and students

SUBJECT DESCRIPTION: Studies of free-jet expansions of binary gas mixtures and their application to chemical kinetic studies of endothermic reactions; crossed molecular beam experiments.

PROGRESS IN BRIEF: We are continuing our studies of free-jet expansions, relevant to rocket exhaust plume physics, with special emphasis now on polyatomics. We are making theoretical progress, by a moment method solution of the Boltzmann equation, in prediction of terminal velocity distributions and internal energy state populations of polyatomic gases in such expansions. A crucial experimental test on N_2 is being prepared in which the rotational state distribution is measured directly by electron beam induced emission, while the velocity distribution is measured simultaneously with our existing time-of-flight techniques.

We have completed our new detection system for the reactive crossed beam experiments. We have reduced the background pressure in the detector by three orders of magnitude and have reduced electrical noise to less than one count per second. We have re-run our $O + CS_2 \rightarrow CS + SO$ experiment, reconfirmed the existence of product SO, and reconfirmed its presence in the collision rebound direction.

After considerable study we have decided not to pursue the metal-oxide reactions with our crossed molecular beam system. This decision was made primarily because we have learned that five other laboratories are already working on these systems with similar techniques. Instead, we have decided to examine other reactions of interest to exhaust plume and atmospheric chemistry. In particular we are preparing to examine the reaction $O + H_2O = OH + OH$ with both $O(^3P)$ and $O(^1D)$ oxygen atoms; for the upper atmosphere $O(^1D)$ is a dominant reactant due to Schumann-Runge photodissociation of O_2. Both species may be present at lower altitudes and in combustion systems. While we can use our existing $O(^3P)$ source, the $O(^1D)$ source must be developed. We intend to do this by photodissociation of N_2O or carbon sub-oxides. We have made preliminary mass-spectrometry studies of the difficulties involved with detection of OH and find that electron energies near 17 eV are necessary to reduce, by one order of magnitude, dissociative ionization of H_2O, which yields OH^+.

There is some indication that reaction with $O(^1D)$ leads to emission in the near infrared. We have the necessary equipment to look at this emission also, which would be of value in evaluating plume signatures.

POSSIBLE APPLICATIONS: Plume physics; chemical laser, Ivy Owl.

PUBLICATIONS:

1. D. R. Miller and D. F. Path, "Non-Equilibrium Slip Effects in Free Jet Expansions of Binary Mixtures at High Temperatures," paper presented at the 8th Rarefied Gas Dynamics Symposium, Stanford, California, July 10-14, 1972.

Topic #13. Shock Tube Measurements of Metal Oxides f-Numbers

INVESTIGATORS: S. S. Penner, K. G. P. Sulzmann and students

SUBJECT DESCRIPTION: Shock-tube measurements of absolute intensities of AlO vibration-rotation bands and of selected Fe-lines

PROGRESS IN BRIEF: The experimental program on iron lines will be terminated within the near future. A report describing f-number measurements on selected weak and strong, high- and low-excitation lines, as well as on selected line widths, will be prepared on the termination of the program.

The following results have been achieved in the AlO program:

1. A theoretical study to construct synthetic infrared spectra, within a yet-to-be-determined scaling factor, has been completed. This work is being prepared for publication (K. G. P. Sulzmann, with computing assistance from H. Chen).

2. Aluminum tribromide has been selected as the source of aluminum in Ar-O_2 mixtures, which will be subjected to controlled shock heating in our all-glass shock-tube system. Published vapor pressure data will be checked shortly in order to assure adequate quality control on the mixture composition.

3. Computer programs to predict LTE gas compositions are being run.

4. The cryogenic observation end for quantitative studies on AlO in the infrared is currently being subjected to calibration tests. These tests will be continued for about six weeks.

No unexpected difficulties have been encountered in this program thus far. We hope to begin actual measurements on AlO-containing mixtures towards the end of March 1973.

POSSIBLE APPLICATIONS: Ivy Owl; plume physics.

PUBLICATIONS:

1. H. Fissan and K. G. P. Sulzmann, "Absorption Coefficients for the Infrared Vibration-Rotation Spectrum of FeO," J. Quant. Spectrosc. Radiat. Transfer 12, 979 (1972).

d. Ionospheric Physics

Topic #24. ELF Wave Propagation

INVESTIGATOR: H. G. Booker

SUBJECT DESCRIPTION: Theoretical investigation of extremely low frequency electromagnetic wave propagation between the earth's surface and the ionosphere.

PROGRESS IN BRIEF: Professor H. G. Booker is continuing his studies of the launching of ELF waves in the earth/ionosphere waveguide, and of a new method for calculating the propagation of such waves.

The paper presented verbally at Williamsburg,[1] as cited in the preceding Semi-Annual Technical Status Report (April 1, 1972-September 30, 1972), has been written up and circulated to various URSI Meeting participants. It will be slightly modified in the light of the anticipated comments, and then submitted to "Radio Science" for publication.

In regard to the subject matter described in the second paragraph of the preceding Semi-Annual Technical Status Report, two sets of print-outs have been received from the computer in Paris. Both contained errors which Professor Booker has identified in such a way that M. Lefeuvre of the Groupe de Recherches Ionospheriques could hopefully locate and correct. (Professor Booker is scheduled to see M. Lefeuvre in Paris on 31 March and 1 April 1973).

POSSIBLE APPLICATIONS: Submarine communication; geophysics and ionospheric physics

PUBLICATIONS:

1. H. G. Booker, "The Ionosphere as the Secondary Conductor of a Transformer at ELF," (paper presented at the URSI Meeting, Williamsburg, Va., December 1972).

Topic #25. Theory of Ionospheric Heating Experiment (see also highlight of major accomplishments in Section II)

INVESTIGATORS: J. A. Fejer and students

SUBJECT DESCRIPTION: Theoretical studies of parametric instabilities related to the ionospheric heating experiment at Arecibo.

PROGRESS IN BRIEF: Professor J. A. Fejer and his students are continuing their studies on a number of problems related to the ionospheric heating experiment. The nature of these problems and general technical approach toward their solution were explained in the preceding Semi-Annual Technical Status Report (pages 29 through 31 in report for period April 1, 1972-September 30, 1872).

POSSIBLE APPLICATIONS: Ionospheric heating experiment; laser interaction with plasmas

PUBLICATIONS:

1. Y.-Y. Kuo and J. A. Fejer, "Spectral Line Structure of Parametric Instabilities," Phys. Rev. Letters 29, 1667 (1972).

2. E. Leer, J. A. Fejer and H. C. Chen, "Parametric Excitation of Electromagnetic Waves in the Ionosphere," submitted to J. Plasma Phys, 1972.

3. J. A. Fejer and Y.-Y. Kuo, "Structure in the Non-linear Saturation Spectrum of Parametric Instabilities," submitted to Physics of Fluids, 1973.

Topic #26. Nonlinear Interactions between Electromagnetic Waves and Plasmas

INVESTIGATORS: G. J. Lewak and students

SUBJECT DESCRIPTION: Theoretical studies of nonlinear interactions between electromagnetic waves and plasmas. (Jointly sponsored by NASA and ARPA, with funding support in the approximate ratio of 60% NASA and 40% ARPA).

PROGRESS IN BRIEF: Professor G. J. Lewak and his students are continuing on their theoretical studies of nonlinear interactions between electromagnetic waves and plasmas as outlined in the preceding Semi-Annual Technical Status Report (pages 31 through 33 in report for period April 1, 1972 - September 30, 1972).

POSSIBLE APPLICATIONS: Ionospheric heating experiments; space probe experiments; laser interaction with plasmas

PUBLICATIONS:

1. G. J. Lewak and J. Ogunlana, "Nonlinear Interaction of Resonant Plasma Oscillations," J. Plasma Phys. 7, 207 (1972).

e. Laser Propagation and Advanced Technology

Topic #14. Nonlinear Transmission of Laser Radiation through Systems Undergoing Bound-Free Transitions

INVESTIGATORS: S. S. Penner and student

SUBJECT DESCRIPTION: Experimental study of anomalous near-ultraviolet laser propagation through molecular gases Cl_2 and NOCl.

PROGRESS IN BRIEF: We have encountered great difficulties in reproducing experimental measurements on NOCl using the doubled-ruby frequency. The origin of this problem is not understood and is being investigated. We are currently proceeding on the assumption that the coherence length of our laser system has changed.

POSSIBLE APPLICATIONS: High-power laser propagation; chemical laser

PUBLICATIONS:

1. R. C. Sepucha and S. S. Penner, "Observations of Anomalous Transparency in Bound-Free Transitions of Cl_2," Phys. Rev. Letters 28, 395 (1972).

2. R. C. Sepucha and S. S. Penner, "Transmission of 3471 Å Laser Radiation through Cl_2 and Cl_2-Inert-Gas Mixtures," (to be submitted to Phys. Rev.).

Topic #19. High-power CW Visible Laser (see also highlight of major accomplishment in Section II)

INVESTIGATORS: S. C. Lin and C. P. Wang

SUBJECT DESCRIPTION: Theoretical and experimental study of high-power CW ion lasers operating in the visible region

PROGRESS IN BRIEF: Professor S. C. Lin and Dr. C. P. Wang are continuing their study of high-power visible laser generation.[1,2] In their recent experiments with argon ion lasers using a 185 cm long segmented metal discharge tube (p. 35 in Semi-Annual Technical Status Report for period April 1, 1972-September 30, 1972), they have reached another new peak in the power output and have also obtained some interesting results on the beam characteristics from this continuous-wave (CW) visible laser operating at a relatively large Fresnel number.[3]

To study the mode structure, both the near-field and the far-field beam intensity profiles are measured by scanning the beam across a small aperture of the photodetector. A typical stable resonance cavity consists of a flat, total reflecting mirror and a 6 m radius-of-curvature, 12% transmitting mirror separated by a distance of 350 cm. Using this resonance cavity, a maximum steady state multi-mode laser output of 125 watts in the blue-green has been obtained. Occasionally, such multi-mode output also reached 150 watts, but this usually resulted in some severe mirror damage.

Because of the high power-density (more than 10^4 w/cm^2, c.w. intracavity) and large Fresnel number (N = 20), the output power coupling and mode control is found to be generally quite difficult. To obtain optimum coupling and good mode control

various other resonance cavity geometries have been investigated. Littrow prism and small aperture have also been used to obtain single-frequency operation and TEM_{00} mode respectively.

POSSIBLE APPLICATIONS: Raman spectroscopy for remote chemical analysis and diagnostics of reactive turbulent flows; underwater technology; sea floor inspection; general high-power visible laser technology

PUBLICATIONS:

1. C. P. Wang and S. C. Lin, "Discharge and Lasing Characteristics of a CW Argon Ion Laser at High Current," AIAA Paper No. 72-711 (1972).

2. C. P. Wang and S. C. Lin, "Experimental Study of Argon Ion Laser Discharge at High Current," Journal of Applied Physics 43, 5068 (1972).

3. C. P. Wang and S. C. Lin, "Beam Characteristics of a Large-Bore High-Power Argon Ion Laser," (paper presented at the Spring Meeting of the Optical Society of America, Denver, Colorado, March 13-16, 1973).

Topic #20. Magnetic Confinement and Efficient Ion Laser Generation

INVESTIGATORS: S. C. Lin and student

SUBJECT DESCRIPTION: Theoretical and experimental study of noble gas ion laser performance under the condition of stable magnetic confinement.

PROGRESS IN BRIEF: Professor S. C. Lin and graduate student T. K. Tio are investigating the prospect of stable magnetic confinement as a means for drastically improving the generation efficiency of ion lasers. Previous studies indicated that superposition of a uniform axial magnetic field (i.e., from a solenoidal current) of suitable strength into the discharge plasma did improve the performance of noble gas ion lasers, but the effect has not been dramatic (typically, a factor of 2 improvement in output power and generation efficiency). This may be attributable to the well known fact that plasmas in uniform axial magnetic fields are susceptible to helical instabilities so that the effectiveness of the confining field is severely limited.

To achieve stable confinement, we proposed to generate the ion laser plasma within a linear, multipole, minimum-B field geometry commonly employed in controlled thermonuclear fusion research. The main experimental apparatus, which consists of a 150 cm long, 10 cm bore water-cooled quartz discharge chamber with external axial confining field windings and internal hexapole stabilizing field windings, has been designed and is currently under construction.

In the theoretical study, we plan to extend the previous works of Lin and Chen for wall-confined plasma columns to the case of minimum-B-field-confined plasma columns.

At the time of writing of this Semi-Annual Technical Status Report, construction of the hexapole plasma confinement apparatus is about half-complete. Theoretical formulation of the kinetic and plasma balance equations for the magnetically-confined, low-pressure arc discharge is also well underway.

POSSIBLE APPLICATIONS: Underwater technology; undersea inspection; isotope separation.

PUBLICATIONS: None yet (on-going doctoral thesis research by graduate student).

Topic #21. Upward Laser Frequency Conversion in Gaseous Media

INVESTIGATORS: S. C. Lin and student

SUBJECT DESCRIPTION: Theoretical and experimental study of transient vibrational/rotational population in polyatomic gases, such as BCl_3 and SF_6, during resonant absorption of high-intensity infrared radiation.

PROGRESS IN BRIEF: Professor S. C. Lin and graduate student J. Morris are studying the problem of transient vibrational/rotational population in polyatomic gases, such as BCl_3 and SF_6, during resonant absorption of high-intensity infrared radiation. The objective is to search for the existence of population inversions between the upper levels of the absorbing vibrational modes and the lower levels of the non-absorbing modes that can be utilized for upward frequency conversion of high-power infrared lasers.

In the experimental program, a two-stage, electrically-pumped CO_2 laser with wavelength selection and magnetically driven shutters

has been constructed to provide an initial source of moderately-intense infrared radiation in the 10.6 μ region. Diagnostic spectroscopy is being set up for monitoring the transient population shifts among the various optically-connected vibrational states of potential interest.

In the theoretical study, coupled rate equations for the many-level system have been set up and trial solutions have been obtained from the computer program, using assumed rate constants. Preliminary results look quite promising.

POSSIBLE APPLICATIONS: High-power lasers in the near-infrared and visible regions; tunable infrared lasers.

PUBLICATIONS: None yet (on-going doctoral thesis research by graduate student).

Topic #22. Kinetics in Electron-Beam-Seeded Gas Lasers

INVESTIGATORS: S. C. Lin and C. P. Wang

SUBJECT DESCRIPTION: Theoretical and experimental study of excitation and population inversion in electron-beam-seeded gas lasers.

PROGRESS IN BRIEF: This is a new research topic recently initiated by Professor S. C. Lin and Dr. C. P. Wang in response to expressed ARPA interest in high-power laser technology, nonlinear laser propagation, laser-induced breakdown, and laser energy coupling.

The use of a high-energy electron beam (up to about 100 kV) for uniform excitation of gas lasers was first suggested by Professor S. C. Lin in 1966 to one of his former graduate students, Dr. R. A. Chodzko, as part of the latter's doctoral thesis investigations. Preliminary calculations and estimates made by Chodzko[1] indicated that the method indeed looked promising but a high-energy electron beam with sufficiently high current capacity for direct pumping of a CO_2-N_2 laser of moderate active volume appeared too expensive to develop so that the effort was discontinued. However, recent intensive works at the AVCO-Everett Research Laboratory[2,3] and elsewhere[4,5] on electron-beam-seeded or electron-beam-pumped gas lasers seem to indicate that the idea was basically sound and attractive. Furthermore, the proposition of using a secondary discharge circuit (i.e., the so-called "sustainer" stage[2,3]) for providing the bulk of the

electrical pumping energy tends to reduce the current requirement and hence the cost of the high-voltage primary electron beam significantly. Thus, relatively high-power, pulsed electron-beam-seeded gas laser can now be built at relatively low cost.

Since the use of electron beam for laser excitation is still in its infancy and the method has been successfully tried only in a few well-known gas mixtures (e.g., CO_2-N_2, H_2, and Xenon), we plan to reactivate our effort in the study of electron-beam-seeded gas lasers. To provide a suitable experimental apparatus for this study, we have recently completed the design of a high-voltage discharge system with a 12-liter active (sustainer) volume. The 100 kV hot-cathode electron beam for seeding the sustainer volume is designed to provide a pulsed beam current density up to about 1 ampere per cm^2 for about 10 μsec duration. A variable and switchable high-voltage supply is also provided for the sustainer section so that both sub-breakdown and super-breakdown discharges can be studied.

As the time of writing of this Semi-Annual Technical Status Report, construction of this experimental apparatus is about half-complete.

POSSIBLE APPLICATIONS: High-power laser technology; nonlinear laser propagation; laser-induced breakdown and interactions.

PUBLICATIONS: None.

References

1. R. A. Chodzko, "Analysis of an Electron Beam Excited CO_2-N_2 Laser," pp. 8-9, and Appendix I, pp. 153-159 in Ph.D. Thesis entitled "Thermal Interaction of a Laser Beam in an Absorbing Gas," University of California, San Diego (1970).

2. J. D. Daugherty, D. H. Douglas-Hamilton, R. M. Patrick, and E. R. Pugh, "Laser or Ozone Generator in which a Broad Electron Beam with a Sustainer Field Produce a Large Area, Uniform Discharge," U.S. Patent No. 3,702,973, filed by the AVCO Everett Research Laboratory, September 17, 1970 (to be granted November 14, 1972).

3. D. H. Douglas-Hamilton, "Dissociative Recombination Rate Measurements in N_2, CO and He," AVCO Everett Research Laboratory, Research Report 343, November 1971.

4. N. G. Basov, V. A. Danilychev, and Yu. M. Popov, "Stimulated Emission in the Vacuum Ultraviolet Region," Soviet Journal of Quantum Electronics, 1, 18 (1971).

5. N. G. Basov, "Soviet Approach to E-Beam Pumping," Laser Focus, 8, 45 (1972).

f. Laser Diagnostics and Interactions

Topic #15. Laser-Induced Stress Wave Propagation in Solids and Liquids (see also highlight of major accomplishments in Section II)

INVESTIGATORS: A. T. Ellis and student

SUBJECT DESCRIPTION: Experimental study of laser-induced stress wave propagation in solids and liquids

PROGRESS IN BRIEF: It was reported earlier (p. 40 in Semi-Annual Technical Status Report for period April 1, 1972-September 30, 1972) that our work under this contract resulted in the discovery that microscopic sized voids present in practically all solid materials cause a significant tensile stress to develop as a very short duration, purely-compressive, stress wave propagates.[1,2] A theoretical treatment of this scattering problem for a linearly elastic, isotropic, homogeneous solid with one void has been completed. Expressions for the scattered stresses and displacements as well as the scattered energy have been obtained. A physical model of the solid accounting for all voids was postulated and was shown to yield results similar to those observed experimentally. The rate of energy scattered is shown to be proportional to the fourth and sixth powers of the incident wave frequency.[3] This scattering effect of microscopic voids appears to have previously been unnoticed although there may be significant practical consequences wherever very high frequency stress waves are present.

Work is continuing on the adaptation of these findings to improved resolution in ultrasonic holography. Mode locked neodymium and ruby lasers have been constructed not only for obtaining higher frequency stresses but also for observing the behavior of these waves in various materials.

POSSIBLE APPLICATIONS: Laser-induced material damage; high-power sonar generation and propagation; acoustic holography.

PUBLICATIONS:

1. M. P. Felix and A. T. Ellis, "Laser-Induced Liquid Breakdown - A Step-by-Step Account," Applied Physics Letters 19, 484 (1971).

2. M. P. Felix and A. T. Ellis, "Stress Pulse Propagation in Solids - A Closer Look at Dispersion," Applied Physics Letters 21, Dec. 1, (1972).

3. M. P. Felix, "Short Duration Stress Pulse Propagation in Solids and Liquids," Ph.D. Thesis, University of California, San Diego, February, 1973.

Topic #16. Laser-Induced Elastic Wave Focusing in Partially Transparent Solids

INVESTIGATORS: W. Nachbar and student

SUBJECT DESCRIPTION: Theoretical study of laser-induced elastic wave focusing in partially transparent solids in one-dimensional geometries.

PROGRESS IN BRIEF: As described in the preceding Semi-Annual Technical Status Report (pages 41 and 42 in report for period April 1, 1972 - September 30, 1972), this is an analytical study of inward-focussing, or implosion, stress waves in solid materials of cylindrical and spherical geometries caused by impulsive internal heating of the material by a laser. Energy levels below the thermal-damage threshold are considered.

Evidence of implosion effects at low energy levels in water were not found in experiments in the UCSD laboratory (Ellis and Felix, 1972), being possibly masked by other effects. We began to look in the past six months at two possible mechanisms for attenuating the pulse height predicated by our analysis. The mechanics are viscoelastic dissipation and the dispersive effect of asymmetry. Neither problem could be solved completely, but indications are that these effects are not critical.

We are now looking at shock wave formation from the inwards focussing stress wave in order to investigate quantitatively the

dynamics of the enlargement of minute imperfections. We will try to use the shock wave solutions of nonlinear hydrodynamics, in conjunction with the linear elastic and linear hydrodynamic solutions already obtained, to get a more physically realistic solution to the implosion problems.

POSSIBLE APPLICATIONS: Detection of small voids and measurement of small radiation absorption coefficients at low energy inputs; study of mechanism for fracture of glass lasers below thermal damage thresholds at moderate energy inputs.

PUBLICATION:

1. W. Nachbar and C.-H. Ho, "Thermally-Induced Elastic Wave Focusing Near a Cylindrical Cavity in a Partially Transparent Solid Under Impulsive Electromagnetic (Laser) Heating," (in preparation for publication).

Topic #17. Impulsive Stress Wave Propagation in Solids

INVESTIGATORS: G. A. Hegemier and student

SUBJECT DESCRIPTION: Theoretical study of stress and deformation states in partially transparent solids subjected to impulsive radiation.

PROGRESS IN BRIEF: Professor G. A. Hegemier and his student have been studying the problem of stress wave propagation and deformation states in partially transparent solids when they are subjected to impulsive radiation, either from an intense X-ray or an intense laser source. So far, they have obtained an exact (i.e., analytic) one-dimensional solution for elastic, viscoelastic, and plastic temperature-dependent solids occupying a half-space. They have also obtained exact two-dimensional solution for an elastic half-space subjected to a cylindrical beam of radiation. Their solutions indicate that one-dimensional simulations may lead to nonconservative results in certain cases.

Even though the one- and two-dimensional geometries are highly idealized, the closed-form (i.e., analytic) solutions they obtained are useful not only for indication of the general character of the propagating stress waves, but also for providing a method for checking large-scale computer codes.

This work will be terminated at the end of the current contractual period (June 30, 1973).

POSSIBLE APPLICATIONS: Simulation of impulsive X-ray or laser radiation-solid interactions; checking of computer codes.

PUBLICATIONS:

1. F. Tzung and G. A. Hegemier, "Stress-Wave Generation in an Elastic Half-Space Subjected to a Cylindrical Beam of Impulsive Radiation," (to be published in the J. Appl. Mech.).

Topic #18. Laser-Induced Plasma Instabilities

INVESTIGATORS: K. A. Brueckner and S. Jorna

SUBJECT DESCRIPTION: Theoretical study of laser-driven instabilities in plasmas (jointly sponsored by the KMS Fusion, Incorporated, and ARPA)

PROGRESS IN BRIEF: With Professor K. A. Brueckner on leave and Dr. S. Jorna's departure from the UCSD campus on October 16, 1972, this work has effectively been terminated after that date. However, one of Professor Brueckner's students, M. Alferieff, is still in the process of finishing up his Ph.D. thesis research on collision broadening of atomic line by neutral hydrogen atoms[2] with partial ARPA funding support until the end of the current contractual period (June 30, 1973).

POSSIBLE APPLICATIONS: Laser and electromagnetic wave propagation through the ionosphere; laser-driven fusion

PUBLICATIONS:

1. K. A. Brueckner, R. A. Cover, P. Hammerling and S. Jorna, "Laser-Driven Plasma Instabilities," (submitted for publication).

2. M. Alferieff, "Collision Broadening of Atomic Line by Neutral Hydrogen Atoms," Ph.D. Thesis, University of California, San Diego, 1973.

Topic #23. Raman Scattering and Advanced Laser Diagnostics

INVESTIGATORS: S. C. Lin, S. S. Penner, C. P. Wang and students

SUBJECT DESCRIPTIONS: Theoretical and experimental investigations on a number of advanced laser diagnostic techniques, including Raman scattering for remote chemical analysis, wideband laser doppler for measurement of instantaneous turbulence velocity in fluid flows.

PROGRESS IN BRIEF: Professors S. C. Lin, S. S. Penner, Dr. C. P. Wang, and a number of their students are carrying out theoretical investigation and experimental development on a number of advanced laser diagnostics techniques that are generally useful in chemical kinetics, gas dynamics, and fluid mechanics studies of interest to ARPA.

Under the supervision of Professor S. C. Lin, undergraduate students J. Levatter and R. Sandstrom have recently developed a precise method for measuring the relative Raman scattering cross sections of various molecular species in gaseous mixtures. This method, which is based on short-pulse laser scattering and photon-counting,[1] has been successfully applied to the measurement of the Raman scattering cross sections relative to that of molecular nitrogen for a number of previously measured and unmeasured species.

Dr. Charles C. P. Wang has made extensive comparison studies of the various optical mixing techniques commonly employed in laser doppler velocimetry and is proposing a new wideband FM-demodulation technique for measurement of instantaneous turbulence velocity in any semi-transparent fluid. He is currently exploring this new technique with the help of undergraduate student D. Snyder.

Dr. Wang is also investigating the possibility of using the laser doppler width associated with the Brownian motion of suspended particles in fluids as a diagnostic tool for particle size determination in two-phase systems. (This, no doubt, would require laser sources of extraordinarily high monochromaticity.)

Under the supervision of Professor S. S. Penner, graduate students T. Jerskey and H. Chen are carrying out the following investigations:

(i) A filter system is being assembled, preparatory to experimental measurements on resonance-Raman scattering by NOCl.

(ii) An attempt is being made to use the magnitude of the scattered signal in laser-Doppler-velocimetry as a diagnostic tool for characterizing a two-phase system (e.g., carbon particles formed in an acetylene-air diffusion flame).

(iii) Theoretical studies have been completed on the basic problems involved in using derivative spectroscopy with tunable-diode lasers on spectral lines with combined Doppler and Lorentz broadening.

(iv) The effect of non-uniform source velocities on Doppler-shifted line structure is being studied theoretically for a conical source flow.

POSSIBLE APPLICATIONS: Concentration and velocity measurements in reactive turbulent flows; underwater technology; advanced diagnostics for high-temperature entrainment and plume experiments

PUBLICATIONS:

1. J. I. Levatter, R. L. Sandstrom and S. C. Lin, "Raman Cross Sections Measured by Short-Pulse Laser Scattering and Photon Counting," Journal of Applied Physics 44, (scheduled for publication in the July 1973 issue).

2. C. P. Wang, "Instantaneous Turbulence Velocity Measurement by Laser Doppler Velocimeter," Appl. Phys. Letters 20, 339 (1972).

3. C. P. Wang, "A Unified Analysis on Laser Doppler Velocimeter," J. Phys. E: Scientific Instruments 5, 763 (1972).

4. C. P. Wang, "Measurement of Turbulence by Optical Mixing Spectroscopy," Proceedings of the Laser Doppler Velocimeter Workshop, Purdue University, March 9-10, 1972 (to be published).

IV. PERSONNEL

Professor S. C. Lin became Principal Investigator on this contract as of February 1972. Personnel involved in the above research areas are listed below. Individuals listed as faculty members or as research scientists are members of the Institute for Pure and Applied Physical Sciences.

Alferieff, Michael	Research Assistant
Bernard, Jay M.	Research Assistant
Booker, Henry G.	Professor of Applied Physics
Brueckner, Keith A.	Professor of Physics
Chen, Helen	Research Assistant
Dehmel, Richard C.	Research Assistant
Ellis, Albert T.	Professor of Applied Mechanics
Erickson, Gary G.	Research Assistant
Fedder, Joel A.	Research Assistant (Received Ph.D. 9/72)
Fejer, Jules A.	Professor of Applied Physics
Felix, Michael P.	Research Assistant (Received Ph.D. 2/73)
Gibson, Carl H.	Associate Professor of Aerospace Engineering
Gilbert, Alan G.	Research Assistant
Hegemier, Gilbert A.	Associate Professor of Applied Mechanics
Helland, Kenneth N.	Research Assistant
Ho, Chih-Horng	Research Assistant
LaRue, John C.	Research Assistant

Lee, Hee-Joe	Research Assistant
Lewak, George J.	Assistant Professor of Applied Physics
Libby, Paul A.	Professor of Applied Mechanics
Lin, Samuel S.	Assistant Research Engineer
Lin, Shao-Chi	Professor of Engineering Physics
McConnell, Steven O.	Research Assistant
Miller, David R.	Assistant Professor of Engineering Physics
Mooradian, Gregory J.	Research Assistant (Receiving Ph.D. 5/73)
Morris, James H.	Research Assistant
Nachbar, William	Professor of Applied Mechanics
Olfe, Daniel B.	Professor of Aerospace Engineering
Penner, S. S.	Professor of Engineering Physics
Poulsen, Peter	Research Assistant
Sulzmann, Klaus G.	Research Engineer
Tio, Tjaw K.	Research Assistant
Tsang, Leslie C. H.	Research Assistant
Van Atta, Charles W.	Associate Professor of Aerospace Engineering
Walters, Dolores A.	Research Assistant
Wang, Charles C. P.	Assistant Research Engineer
Winant, Clinton D.	Assistant Research Engineer
Williams, Forman A.	Professor of Engineering Physics